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Technology Standardization and Marketing Expenditures for New Products

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This paper focuses on a firm's technology adoption decision, whereby the new technology affects the way in which customers interact with that firm's product. We formulate a non-cooperative game-theoretic framework to investigate the conditions under which two competing firms should adopt the new technology, taking into account this adoption's influence on marketing expenditures. We analyze how managers should select technologies based on the preferences of new or existing customers and demonstrate when a firm should select the new technology regardless of its rival's technology choice. We show that technology standardization around the new technology may be a Nash equilibrium even if there is no coordination, and that coordination increases profits if the technology decision depends solely on the preferences of new customers. Overall, existing customers are a greater barrier to new technology adoption than new customers.

Keywords: Technology Adoption, Marketing Expenditures, Game Theory

1. Introduction

The time lag between new versions of high-tech products has been steadily decreasing (Mahajan et al. 1993). In the personal computing industry, Hua and Wemmerlöv (2006) found that improving a product's technology frequently to stay near the top in product advantage leads to increased sales and market share. Technologies such as enterprise resource planning (ERP) software and radio-frequency identification (RFID) chips are increasingly being implemented to increase sales and profits in both high- and low-tech products and services.

The decision to adopt a new technology becomes even more important if the product itself is new, as making the right decision can increase market share and the speed at which the product diffuses to customers. A technology adoption success story is the wireless Internet industry. Major manufacturers had to decide what wi-fi technology standard would be used to transmit wireless Internet services (Goldstein 2004). As firms cooperated in choosing a standard, no firm had to be concerned with rivals gaining competitive advantages from choosing a different technology. This common standard also eliminated the risk to potential customers of buying from a firm with inferior wireless technology, and thus large firms such as Intel rapidly implemented wireless technology in their products.

However, the wrong technology choice may doom the new product. In the nascent high-resolution DVD industry, movie production firms and manufacturers are choosing between the Blu-Ray and HD-DVD formats. At this time, few high-resolution DVD discs and players have been purchased. If those who have yet to purchase prefer one format over the other, firms that chose the wrong one are likely to incur significant losses in sales, obsolete DVD inventory and production equipment. Firms that chose the winning technology may realize larger profits than if they had cooperated in setting a common format; or they may be financially weakened by competition over format and unable to take advantage of their victory. A firm must thus consider carefully the risks and rewards associated with choosing the same technology as its rival.

In this paper we examine the effects of technology adoption on new product sales. A well-chosen technology can add to a firm's profits via sales by luring customers from rivals or by attracting new customers (i.e. those who are currently not purchasing) to the industry. The new technology may harm the firm if it causes new customers to become less likely to purchase, or existing customers who have finally understood the product balk at having to re-master it. Unlicensed restaurants now rely on Internet invitation systems in addition to traditional word-of-mouth methods. The adoption of this technology has attracted new customers, but has also driven away existing customers who preferred the unlicensed restaurants for their exclusivity (Karp 2006). Because of examples like this and our focus on new products, we separate the customer pool into existing and new customers. Existing customers tend to be early adopters (Moore 2000) and new customers still require information on the firm and its product (Dorf and Byers 2005); the costs and benefits associated with each group of customers are by nature different.

We thus ask: *Given its impact on profits, sales, and marketing expenditures, and given the effect of a rival's technology decision, when is a new technology profitable to adopt?* We

propose a two-stage framework in which a new technology is offered to two profit-maximizing firms selling a new product. We focus on individual sales rather than customers, as one customer may account for several sales. In the first stage, the firms are given the simultaneous opportunity to adopt the new technology. Standardization occurs when both firms select the same technology (new or old), whereas diversification occurs when they select different ones. In the second stage, each firm chooses marketing expenditures targeted toward new customers and the existing customers of the other firm. The effectiveness of marketing expenditures (different for existing and new customers) may change if one or both firms adopt the new technology. Thus, second stage marketing decisions are influenced by first stage technology decisions.

We contribute to the marketing literature by examining the sensitivity of marketing expenditures (and resulting sales and profits) with respect to technology adoption decisions and changes in market conditions (e.g. sales retention). We observe that an increase in a firm's existing sales may have a positive or negative effect on its and the rival's profits. We also describe under what conditions the new technology should be adopted, and consider whether coordination between firms increase profits. §2 reviews the pertinent literature in marketing and technology adoption, whereas §3 describes the decision model. The optimal marketing decision is highlighted in §4 and the equilibrium concept for the technology decision described in §5. Scenarios for optimal technology decisions are investigated in §6 and §7, while §8 offers some managerial implications and future work.

2. Relevant Literature

We first examine the literature on technology adoption and its limitations on modeling the effect of this adoption on sales. We subsequently examine the marketing literature that

studies the effects of technology adoption on sales, and offer a rationale for modeling these effects separately on new and existing sales.

2.1 Technology Adoption

Several benefits exist for adopting new technologies. Gimenez (2006) argues that new technologies increase the quality of outputs or lower production costs. A new technology can also make a product “fashionable.” Peters (1992) argues that all firms need to be “fashion-conscious” in developing new products. Also, positive novelty effects that ramp up existing sales may occur when a firm is the only one in the industry to adopt the new technology. Further, a new technology can make a product more valuable because it is easier for suppliers to create complements to accompany it. GE Fanuc Automation chose standard modular architectures for its industrial controllers, which allowed other component manufacturers to develop complementary products for the industrial controllers (Sanchez and Collins 2001).

Technology games tend to stress coalition behavior and costs. Amaldoss and Rapaport (2005) offer a two-stage game in which firms cooperatively invest in their chosen network to develop products and then compete against other networks for customers. Axelrod et al. (1995) assumes that firms do not want to be in coalitions with rivals and that they prefer large alliances to small ones. Belleflamme (1998) allows for negative effects due to joining a coalition and considers incomplete information games, whereas Gimenez (2006) examines the choice of investing in new technology by including learning costs. Van Wegberg (2004) studies how entrant and incumbent firms might play a game in choosing technology for new products.

Instead, a key part of our model is exploring new technology adoption, especially standardization around the new technology. A full exposition of the advantages and disadvantages of standardization versus diversification can be found in Besen and Farrell (1994).

If the industry chooses a common technology for new products, it may lead to higher profits (van Wegberg 2004, Aldrich and Fiol 1994). However, it may be difficult to determine which technology should be chosen for standardization. Aldrich and Fiol (1994) argue that, for a nascent industry, not having product technology standardized lowers the perceived reliability or legitimacy of the product to outsiders. Typically, firms have a common technology – the empirical pattern is that industries converge to a dominant design (Anderson and Tushman, 1990). Aldrich and Fiol (1994) add that firms with easy-to-imitate products have a greater incentive to cooperate on a technology standard.

However, Katz and Shapiro (1985) show that it may not be beneficial for some firms if all firms standardize. Indeed, technology standardization may be unprofitable when firms are able to sustain high enough growth by themselves. Rice and Galvin (2006) noted that Nokia and Ericsson’s lack of technology compatibility early on was partly because of high growth expectations at both firms. Neither firm thought common standardization was necessary for its new product to be successful. Therefore, both firms in our model may wish to have different technologies, and we contribute further to the literature by modeling this possibility.¹

2.2 Customer Reactions to New Technology

The effects of new technology on sales have been underrepresented in previous literature, especially the consideration of separate effects on new and existing sales. Axelrod et al. (1995) mention in passing that technology affects market share, but do not explicitly model its effects on customers. Much of the work has been focused on industries where there are network externalities (a.k.a. positive demand externalities); the product with the most users, or the technology being used by the most firms, is the most valuable. Thus, the focus has been on

¹ We further note that the technology-search literature (e.g. Lippman and McCardle 1991, 1987), which models over time searching for a new technology of uncertain value, do not model marketing effects and/or firm competition.

product compatibility, whereby if a product does not have enough sales, the firm has greater incentive to make that product compatible to other firms' product (Katz and Shapiro 1985).

However, Katz and Shapiro (1985) also demonstrate that this compatibility may lower other firms' profits. Farrell and Saloner (1986) study this from a time of adoption perspective and point out that older customers have less surplus value from their purchase than newer customers who purchase when there are more users of the product. Finally, Farrell and Saloner (1988) and van Wegberg (2004) study mechanisms by which firms could standardize new technologies, such as an individual firm taking the lead and setting a technology standard, or cooperative standard-setting among all firms. Because we assume that the product itself is new, we contribute by segmenting sales into existing and new. We also contribute by examining customer rather than firm preferences for technology, whereby customer preferences may result in positive externalities for one firm but negative externalities for another.

2.3 Marketing Efforts

We choose to model marketing to new and existing customers separately, because the attitudes of these two groups towards a change in technology is likely to be different. Farrell and Saloner (1986) provide insight into the phenomenon of balancing new and existing users by focusing on products where the new technology is incompatible with the old product. They also model whether the firm adopts the new technology expecting new customers to be the primary source of sales, or expecting old customers to switch from the product with the old technology. However, they neither model the case where the new technology is preferred by existing customers nor do they focus on the marketing aspects of the decision.

There are research in marketing that do separate the effectiveness of marketing expenditures of each firm depending on whether the sale being targeted is new or existing,

including Angelis and Lévesque (2006), Bass et al. (2005), and Wrather and Yu (1979). We add insights by considering technology adoption decisions and how these decisions may simultaneously change the marketing effectiveness on both new and existing customers.

3. Model Formulation

3.1 Decision Variables

In the first stage, each firm (firm i , firm j) decides whether to retain the old technology or switch to the new one. The technology choice is modeled by binary decision variables $\varphi_i \in \{0,1\}$ and $\varphi_j \in \{0,1\}$, respectively, where 0 is the choice to retain the old technology and 1 the choice to switch to the new technology. The unit profit margin is denoted by π_i for firm i and π_j for firm j . Because of our desire to concentrate on the effects of technology adoption on marketing, we assume that there is no effect on unit profit margin due to new technology adoption.

In the second stage – i.e. after the technology adoption decisions – firms choose their marketing expenditures. Firms are assumed to have a different effectiveness (i.e. return on expenditures) for existing and new sales. Thus, firms have different expenditures aimed at each type of sale, as in Angelis and Lévesque (2006), Bass et al. (2005), and Wrather and Yu (1979). Expenditures used to acquire existing sales of the other firm are labeled *share* expenditures, whereas those used to attract new sales are labeled *growth* expenditures. Firms i and j select share expenditures a_i and a_j , and growth expenditures g_i and g_j , respectively, in order to maximize total profits. Table 1 summarizes notation for firm i ; decision variables, functions and parameters are denoted the same for firm j with the appropriate change in subscript.

----- Insert Table 1 about here -----

3.2 Profits and Sales Functions

We focus on firm i 's profits and sales function because those for firm j can straightforwardly be derived by symmetry. Firm i 's existing sales are denoted $S_{i,0}$; those existing sales are totaled at the beginning of the first stage, before the technology decision is made. After the technology and marketing decisions are made, total sales at the end of the second stage result at a value of S_i – we subsequently introduce the sales function S_i . Firm i 's profit is $\pi_i S_i$ and its objective is to maximize that profit net of marketing expenditures, P_i , that is,

$$\text{Max}_{\varphi_i \in \{0,1\}, a_i, g_i} P_i = \text{Max}_{\varphi_i \in \{0,1\}, a_i, g_i} \pi_i S_i - a_i - g_i \quad \text{with} \quad a_i, g_i, S_i \geq 0. \quad (1)$$

The model partitions all potential industry sales into three segments: $S_{i,0}$ and $S_{j,0}$, which are the existing sales for each firm, and new potential sales that do not belong to either firm. We assume a market (industry) ceiling as in Fruchter (1999) and Erickson (2003) and denote that ceiling as m_0 . Thus, new sales account to $m_0 - S_{i,0} - S_{j,0}$. We follow the example of Erickson's (2003) diffusion model and identify the external and internal influences which direct new sales to a firm. The external influence is the firm's own growth expenditures, while the internal influence is positive word-of-mouth between the firm's existing customers and new customers.

We first introduce the external influence term. Firms i and j allocate growth expenditures toward attracting new sales that have an impact of, respectively, $g_i^{1-\mu_i}$ and $g_j^{1-\mu_j}$. Exponent terms $\mu_i \in (0,1)$ and $\mu_j \in (0,1)$ highlight the decreasing-returns nature of growth expenditures. Further, the effectiveness of growth expenditures represents the percentage of new sales a firm realizes based on these expenditures, due to its marketing ability and the receptiveness of new sales to that ability. This effectiveness depends on the technology chosen by each firm and is thus denoted by $\beta_i(\varphi_i, \varphi_j) \in (0,1)$ for firm i and $\beta_j(\varphi_i, \varphi_j) \in (0,1)$ for firm j . Specifically, firm

i 's growth expenditure effectiveness is $\beta_i(0,0)$ when both firms remain with the old technology, $\beta_i(1,0)$ if only firm i chooses the new technology, $\beta_i(0,1)$ if only firm j chooses the new technology, and $\beta_i(1,1)$ if both firms switch to the new technology.

As for the internal influence, new sales may also enter firm i via word-of-mouth effects between its existing and new customers. Word-of-mouth effects are accentuated by existing sales and thus represented by $\varepsilon_i S_{i,0}$. In turn, word-of-mouth effects (not affected by the expenditures of either firm) are applied toward new sales to yield a total effect of $\varepsilon_i S_{i,0} [m_0 - S_{i,0} - S_{j,0}]$. In other words, the product of $S_{i,0}$ and $m_0 - S_{i,0} - S_{j,0}$ represents the maximum sales interaction possible: each existing sale of firm i interacts with each new sale. That maximum interaction is weighed by ε_i . We next introduce the terms of the sales function that account for share (as opposed to growth) expenditures.

Firms i and j allocate share expenditures toward attracting new sales that have an impact of, respectively, $a_i^{1-\lambda_i}$ and $a_j^{1-\lambda_j}$ ($\lambda_i \in (0,1)$ and $\lambda_j \in (0,1)$ highlight the decreasing-returns nature of these expenditures). Effectiveness of these expenditures represents the percentage of a rival's existing sales a firm is able to attract based on its own share expenditures, due to its marketing ability and the receptiveness of the rival's existing sales to that ability. For firm j , this effectiveness depends on the technology chosen and is denoted by $\rho_j(\varphi_i, \varphi_j) \in (0,1)$; similarly $\rho_i(\varphi_i, \varphi_j) \in (0,1)$ for firm i . The dependence of share expenditure effectiveness on technology choice is similar to that of growth expenditure effectiveness.

In addition to the sales lost to firm j , we model the change in existing sales of firm i due to sales departing the industry altogether. Existing customers decide not to purchase from the industry again due to non-expenditure factors such as forgetfulness or product and market

characteristics. The ordering of events is that first, existing customers decide whether to remain with their firm or leave the industry, and then, firms invest in share expenditures to acquire the retained sales of the other firm. Let $\delta_i \in [0,1]$ measure the percentage of existing sales that are retained by firm i , and $[1-\delta_i]$ the percentage that depart. Firm i targets the retained existing sales of firm j , i.e. $\delta_j S_{j,0}$ rather than $S_{j,0}$.

Consequently, firm i 's sales function can be expressed as

$$S_i = \left[1 - \rho_j(\varphi_i, \varphi_j) a_j^{1-\lambda_j}\right] \delta_i S_{i,0} + \rho_i(\varphi_i, \varphi_j) a_i^{1-\lambda_i} \delta_j S_{j,0} + \left\{ \beta_i(\varphi_i, \varphi_j) g_i^{1-\mu_i} + \varepsilon_i S_{i,0} \right\} \{m_0 - S_{i,0} - S_{j,0}\}. \quad (2)$$

The first term is firm i 's addition of its existing sales due to sales retention and its loss of existing sales to the share expenditures of its rival, firm j . The second term is firm i 's addition of the rival's existing sales via share expenditures. The third term measures firm i 's addition of new sales through growth expenditures and its addition of new sales due to word-of-mouth effects.

4. Second Stage Solution and Sensitivity of Firm Performance

We proceed to solve the two-stage game using the commonly used rollback technique (Dixit and Skeath 1999). We begin by solving the game at the second stage for optimal share and growth expenditures. Details appear in the appendix. We then calculate the relationship between these expenditures, and conduct sensitivity analysis on the resulting profits and sales to further investigate the effectiveness of a variety of strategies to improve firm performance. The results of our sensitivity analysis are summarized in Table 2, with key results formally described in Propositions 1 to 3. The results in Proposition 1 are straightforwardly obtained from taking the partial derivatives of optimal share and growth expenditures (i.e. the right-hand side of equations 3 and 4 below) with respect to each parameter, holding all other parameters constant. For Propositions 2 and 3, optimal expenditures are substituted into sales and profits functions. Partial

derivatives of these functions are then taken with respect to each parameter. Hence, our further analysis refers to what actions should be taken when optimal expenditures are implemented.

----- Insert Table 2 about here -----

4.1 Optimal Marketing Expenditures

Optimal share and growth expenditures for firm i are, respectively,

$$a_i^* = \left[\pi_i \rho_i(\varphi_i, \varphi_j) [1 - \lambda_i] \delta_j S_{j,0} \right]^{1/\lambda_i} \quad (3)$$

$$\text{and } g_i^* = \left[\pi_i [1 - \mu_i] \beta_i(\varphi_i, \varphi_j) [m_0 - S_{i,0} - S_{j,0}] \right]^{1/\mu_i}. \quad (4)$$

We examine equations (3) and (4) assuming interior solutions.² Optimal growth and share expenditures are likely to change when a key model parameter is increased or decreased. We first highlight from Table 2 the effects of environmental changes on a firm's marketing expenditures. An increase in a firm's unit profit margin should increase both share and growth expenditures, because the firm obtains a higher return on each dollar spent in marketing. On the other hand, an increase in its existing sales should decrease growth expenditures, as there are now fewer sales for that firm to attract than before. Also, if the firm notices an increase in its effectiveness in share or growth expenditures, it should increase the affected expenditure. The rationale is that each dollar invested in that expenditure has a higher return in terms of sales than before the

² Given the sales function in (2), total sales at the end of the second stage for a firm must be positive and not exceed the market ceiling; i.e., $S_i \in (0, m_0)$, $S_j \in (0, m_0)$, and $S_i + S_j < m_0$. Thus, share and growth expenditures should be bounded so that a firm cannot acquire more than 100% of its rival's existing sales and no new sale is attracted twice. If none of the constraints are violated, optimal expenditures are as in (3) and (4) and obtained by using the first-order derivative of the objective function with respect to expenditures. If any one of the above constraint does not hold,

$$a_i^* \leq \left[\frac{1}{\rho_i(\varphi_i, \varphi_j)} \right]^{1/(1-\lambda_i)} \quad \text{or} \quad g_i^* \leq \left[\frac{1 - g_j^{1-\mu_j} \beta_j(\varphi_i, \varphi_j) - \varepsilon_i S_{i,0} - \varepsilon_j S_{j,0}}{\beta_i(\varphi_i, \varphi_j)} \right]^{1/[1-\mu_i]}, \quad (*)$$

depending on which constraint(s) is (are) violated. However, note that implementations of (*) mean that the new product competition is over, as either $S_j = 0$ or $S_i + S_j = m_0$, respectively. Thus, we focus on the unconstrained solutions of the expenditure variables for subsequent analysis.

increase. Because sales retention and word-of-mouth effects are independent of the firm's expenditures, a change in either should not change expenditures. In addition, the market ceiling, an environmental feature that is the same for both firms, also has an expected effect on growth expenditures: the more the sales in the market, the more money both firms should spend.

The changes just described on a firm's marketing expenditures are intuitive. More challenging are the changes in the environment of a rival that force the firm to change its marketing expenditures. Table 2 shows that a firm should react to increases in a rival's sales retention or existing sales by increasing its investment in acquiring the sales of that rival. It may not be necessary, however, for the firm to increase its total marketing expenditures. Formally,

Proposition 1: A firm's total marketing expenditures is expected to increase when

- (a) sales retention increases for its rival (i.e. δ_j is increased); or
- (b) existing sales increase for its rival (i.e. $S_{j,0}$ is increased) if and only if the ratio of share to growth expenditures (i.e. a_i^* / g_i^*) exceeds a threshold.

Proposition 1(a) recommends an increase in total marketing expenditures when a firm's rival increases its sales retention (and thus increases its existing sales). In particular, as seen in Table 2, the firm should increase its investment in share expenditures to match the opportunity for increased acquisition of the rival's sales. The firm should not change its investment in growth expenditures, since the total number of new sales has not changed (we assumed that when existing sales depart a firm, they exit the market as a whole).

In contrast, Proposition 1(b) suggests that a firm be cautious with respect to increasing total marketing expenditures in response to an increase in the existing sales of its rival. The direction of change from Table 2 shows an increase for share expenditures but a decrease for growth expenditures. To evaluate whether or not the benefits from an increase in share

expenditures exceeds the losses from a decrease in growth expenditures, the firm should examine

the sales ratio $\frac{\lambda_i S_{j,0}}{\mu_i [m_0 - S_{i,0} - S_{j,0}]}$. This ratio provides the firm with a benchmark of how its

investments in share and growth expenditures compare with the actual opportunity – that is, existing sales of its rival, new sales, and the diminishing returns from both types of sales.

For instance, suppose the product of (diminishing) returns on share expenditures and its rival's existing sales ($\lambda_i S_{j,0}$) is twice as large as the product of returns on growth expenditures and new sales ($\mu_i [m_0 - S_{i,0} - S_{j,0}]$). If the firm is spending over twice as much on share expenditures than on growth expenditures, then total marketing expenditures should increase. Hence, before a firm concludes that its rival's increase in existing sales means that the firm must obtain additional funds with which to target those sales, it should also consider its growth expenditures, diminishing returns on share and growth expenditures, and the size of its two sales sources (new customers and its rival's existing customers). The firm may be able to pay for the increased share expenditures by decreasing growth expenditures and still save money.

4.2 Sensitivity of Firm Performance

Firm performances are affected by environmental changes. As far as its own environment is concerned, increases in unit profit margin, effectiveness of share or growth expenditures, sales retention, word-of-mouth effect, or market ceiling all increase a firm's sales and profits, as expected and summarized in Table 2. As far as the environment of its rival is concerned, if that rival experiences an increase in unit profit margin or effectiveness of share expenditures, then the firm's performance should decrease. The rival should use some of its increase to augment share

expenditures, which results in the firm losing sales (and profits).³ On the other hand, conventional strategy based on first mover advantages (Lieberman and Montgomery 1988) and economies of scale (Frank 2000) seems to indicate that a firm would prefer its own sales to be as large as possible and the sales of its rival as small as possible. We suggest that a firm exhibits higher returns on its share expenditures if its rival exhibits higher existing sales. Formally,

Proposition 2:

- (a) An increase in a firm's existing sales (i.e. $S_{i,0}$ is increased) does not necessarily lead to increased sales or profits for that firm.
- (b) An increase in the existing sales of that firm's rival (i.e. $S_{j,0}$ is increased) does not necessarily lead to decreased sales or profits for that firm.⁴

For part (a), an increase in its existing sales may yield lower performance because these existing sales lessen the profits from its growth expenditures (there are less new sales) *and* increase the share expenditures of its rival. An increase in a firm's existing sales does not increase its return on marketing expenditures, but improves the number of sales that the firm can retain and the word-of-mouth effect of its existing sales on new sales. Hence, the condition underlying part (a) is a threshold. If profits and sales *not* due to marketing expenditures exceed that due to marketing expenditures, then the firm improves its performance when its existing sales increase.⁵ Thus, if a firm's existing sales are higher than it can sufficiently retain (whether

³ But a firm's performance should not be altered by a change in the growth expenditure effectiveness of its rival or word-of-mouth effect (both of which influencing how many new sales the rival can conquer). This holds because its rival's increase does not decrease the firm's attraction of new sales; there are enough new sales to go around.

⁴ Equivalently, (a) a decrease in a firm's existing sales (i.e. $S_{i,0}$ is decreased) does not necessarily lead to decreased sales or profits for that firm or (b) a decrease in the existing sales of that firm's rival (i.e. $S_{j,0}$ is decreased) does not necessarily lead to increased sales or profits for that firm.

⁵ I.e., the firm improves its profits when its existing sales increase if and only if (the condition is similar for sales)

$$\delta_i + \varepsilon_i [m_0 - 2S_{i,0} - S_{j,0}] > \frac{[\pi_j S_{i,0}]^{\frac{1-\lambda_j}{\lambda_j}}}{\lambda_j} [\rho_j [1-\lambda_j] \delta_i]^{\frac{1}{\lambda_j}} + \frac{\{\pi_i [m_0 - S_{i,0} - S_{j,0}]\}^{\frac{1-\mu_i}{\mu_i}}}{\mu_i} [[1-\mu_i] \beta_i]^{\frac{1}{\mu_i}}.$$

that means the sales are departing to a rival or the industry) or are lowering the firm's ability to attract new sales, increasing existing sales may lower that firm's profitability. The firm should not aim at maximizing sales without first guaranteeing that it can successfully retain those sales.

For part (b), recall from Proposition 1 that increased existing sales for the rival may yield increased or decreased optimal marketing expenditures for the firm. The rationale for Proposition 2(b) is similar to that of Proposition 1(b).⁶ The more existing sales a firm acquires from share expenditures as opposed to new sales from growth expenditures or word-of-mouth, the more likely it is to increase profits from an increase in the rival's existing sales. On the other hand, if a firm is concentrating on growing via new sales, any increase in its rival's existing sales decreases the number of new sales available and lowers the firm's return on growth expenditures.⁷

Implications follow from the application of Propositions 2. When a decrease in its own – or an increase in its rival's – existing sales increases a firm's profits, that firm has a counter-intuitive incentive to possess as few existing sales as possible relative to its rival. If its rival is experiencing rapid sales growth, such a firm should focus on improving the effectiveness of its share expenditures so as to increase acquisition of rival sales. This may portray a firm that is better suited to follow its rival rather than being a first mover, as with Microsoft and the Internet browser market. Netscape did much of the early selling of Internet browsers, and Microsoft then aggressively acquired much of that market share once there was significant demand. When an increase in its own – or a decrease in its rival's – existing sales increases a firm's profits, that

⁶ That is, an increase in the existing sales of the firm's rival increases that firm's profits if and only if

$$\frac{\left[\frac{\pi_i S_{j,0}}{\lambda_i}\right]^{\frac{1-\lambda_i}{\lambda_i}}}{\lambda_i} \left[\rho_i [1-\lambda_i] \delta_j\right]^{\frac{1}{\lambda_i}} > \frac{\left\{\pi_i [m_0 - S_{i,0} - S_{j,0}]\right\}^{\frac{1-\mu_i}{\mu_i}}}{\mu_i} \left[[1-\mu_i] \beta_i\right]^{\frac{1}{\mu_i}} + \pi_i \varepsilon_i S_{i,0}.$$

⁷ It can be further broken down by the terms in (3) and (4); a firm is more likely to increase profits from the rival's increase in existing sales if it has high effectiveness of share expenditures or its rival has high sales retention. An increase in market ceiling, existing sales, effectiveness of growth expenditures, or word of mouth makes it more likely that a firm decreases profits from the rival's increase in existing sales.

firm's new product can survive by itself as sales and profits are increased. In addition, driving its rival to zero sales would not hurt the firm. The firm should thus focus on increasing existing sales retention and rewarding existing customers for bringing in new business rather than investing in improving the effectiveness of share and growth expenditures.

We further note that an increase in the market ceiling is profitable to both firms (more available sales for the new product equals more profits), but less expected is the observation that an increase in sales retention for the rival is also profitable to both firms. If the rival can retain sales, the firm is able to compete for the business of those sales and improve its performance. But if the rival cannot retain its existing sales, both firms suffer decreased profits. Formally,

Proposition 3: If the sales retention of the firm's rival increases (i.e. δ_j is increased), then that firm's sales and profits increase.

We next solve the game in the first stage for the technology adoption decision, utilizing optimal expenditure amounts calculated from this second stage. From the first stage, we examine how profits change when both firms simultaneously change their growth or share expenditure effectiveness due to technology adoption. The rollback technique used herein guarantees that the technology adoption decision is optimal for the second as well as the first stage.

5. First Stage Solution: Equilibrium Concept

Both firms simultaneously decide whether or not to adopt the new technology. Four possible technology sets exist, representing the two possible technology choices for each firm. For instance, when firm i does not adopt the new technology but firm j does, the technology set is $\{0,1\}$, and $P_i(0,1)$ and $P_j(0,1)$ denote the profits of firm i and firm j , respectively. Assuming that each firm has implemented optimal marketing expenditures from the second stage, in the

first stage firm i selects whether to retain the old technology (i.e. $\varphi_i = 0$) or adopt the new technology (i.e. $\varphi_i = 1$) so as to maximize its profit. That is,

$$\text{Max}_{\varphi_i \in (0,1)} P_i(\varphi_i, \varphi_j) = \text{Max}_{\pi_i} \left[\begin{array}{l} \delta_i S_{i,0} + \lambda_i [\pi_i [1 - \lambda_i]]^{\frac{1-\lambda_i}{\lambda_i}} \left[\rho_i(\varphi_i, \varphi_j) \delta_j S_{j,0} \right]^{\frac{1}{\lambda_i}} \\ - [[1 - \lambda_j] \pi_j]^{\frac{1-\lambda_j}{\lambda_j}} \left[\rho_j(\varphi_i, \varphi_j) \delta_i S_{i,0} \right]^{\frac{1}{\lambda_j}} + \varepsilon_i S_{i,0} [m_0 - S_{i,0} - S_{j,0}] \\ + \mu_i [\pi_i [1 - \mu_i]]^{\frac{1-\mu_i}{\mu_i}} \left[\beta_i(\varphi_i, \varphi_j) [m_0 - S_{i,0} - S_{j,0}] \right]^{\frac{1}{\mu_i}} \end{array} \right]. \quad (5)$$

Although each firm attempts to maximize its profits, an increase in a firm's profits does not necessarily lead to a decrease in its rival's profits. Consequently, this is a non-zero sum game.

A *strategy* describes which technology a firm should select given what it knows about the effect of each technology on its and the rival's profits. The firm's strategy may be to randomly select a technology, select a technology conditionally based on the technology the rival might select, or to always select a particular technology. Formally, the three types of strategies are

mixed strategy: the firm cannot determine with certainty which technology choice it should select, which may happen even if the firm knew its rival's technology choice;

pure strategy: the firm can determine with certainty which technology choice is more profitable, if it knew its rival's technology choice; *or*

dominant strategy: the firm can determine with certainty which technology choice is more profitable, regardless of its rival's technology choice.

If a firm possesses two pure strategies, both recommending the same technology, then that technology dominates regardless of the rival's choice. If it possesses two pure strategies, both recommending different technologies, and cannot anticipate the rival's choice, then that firm's strategy is mixed. Also, a firm may have a pure strategy for one of the rival's choice and a mixed strategy for the other choice.

For our solution concept we use Nash equilibrium. Specifically, after both firms make their decision, each is informed of the other's decision. A firm *regrets* its decision if, given its rival's decision, that firm would have increased profits by selecting the other technology. If, for a given technology set, neither firm increases profits by switching to the other technology while the other firm does not switch, then that set is a Nash equilibrium. A Nash equilibrium set is *regret-proof*, i.e. neither firm regrets its decision after learning what the other firm has chosen. We confine our analysis to scenarios where there is at least one pure strategy Nash equilibrium.⁸

The game starts with both firms using the old technology. If coordination is forbidden, the potential outcomes of the game are determined with certainty under the following conditions.

standardization around the old technology: the technology set $\{0,0\}$ is regret-proof;

technology diversification, firm i retains the old technology: the technology set $\{0,1\}$ is regret-proof but $\{1,0\}$ is not;

technology diversification, firm i adopts the new technology: the technology set $\{1,0\}$ is regret-proof but $\{0,1\}$ is not;

standardization around the new technology: the technology set $\{0,0\}$ is not regret-proof but $\{1,1\}$ is.

Mathematical expressions for the sufficient conditions under which each outcome occurs with certainty (a pure strategy Nash equilibrium) are presented in Table 3. Table 3 shows that since $\{0,0\}$ is the starting point of the game, $\{0,0\}$ is the outcome when regret-proof even if there is another pure strategy Nash equilibrium (i.e. $\{1,1\}$). For the other technology sets to be the outcome, at least one firm must have a dominant strategy.

----- Insert Table 3 about here -----

⁸ Pure as opposed to mixed strategy Nash equilibrium in which one or both firms randomly select a technology because neither technology choice is optimal, given the technology choice(s) of the other firm.

6. Technology Decision and New Sales Attraction

We first illustrate how the firm's technology adoption decision affects profits via a change in growth expenditure effectiveness, and then offer guidance as to the profit-maximizing technology decision. If, on average, new customers perceive the product as being more attractive after a technology change, then growth expenditure effectiveness increases. According to Table 2, this increase augments a firm's growth expenditures, sales and profits, but has no effect on the rival's profits. The firm's technology adoption decision thus only depends on the direction of the change in its own growth expenditure. Formally, $P_i(\varphi_i, \varphi_j) > P_i(\varphi'_i, \varphi'_j)$ if and only if $\beta_i(\varphi_i, \varphi_j) > \beta_i(\varphi'_i, \varphi'_j)$, where the technology sets $\{\varphi_i, \varphi_j\}$ and $\{\varphi'_i, \varphi'_j\}$ are different. Selecting the first-stage technology that leads to larger growth expenditure effectiveness allows the firm to experience higher returns from second-stage growth expenditures.

There are 24 distinct orderings for $\beta_i(\varphi_i, \varphi_j)$; e.g. $\beta_i(1,0) > \beta_i(1,1) > \beta_i(0,0) > \beta_i(0,1)$. We refer to the largest $\beta_i(\varphi_i, \varphi_j)$ as the *maximum growth expenditure effectiveness* (i.e. acquiring the maximum number of new customers) and the smallest $\beta_i(\varphi_i, \varphi_j)$ as the *minimum growth expenditure effectiveness*. To limit duplication, we focus on orderings where adopting the new technology yields maximum effectiveness. We report on optimal strategies based on a firm's ordering, assumed known by that firm, and consider the role of coordination in decision-making. We examine orderings that lead to dominant strategies. The resulting proposition yields guidelines that, if satisfied, allow a firm's manager to select a regret-proof technology regardless of her rival's decision. Formally,

Proposition 4: When a firm cannot anticipate its rival's technology choice, adopting the new technology is a dominant strategy for that firm if and only if

- (a) that firm's maximum growth expenditure effectiveness results when it adopts the new technology (i.e. $\{1,0\}$ or $\{1,1\}$);
- (b) that firm's minimum growth expenditure effectiveness results when it retains the old technology (i.e. $\{0,0\}$ or $\{0,1\}$); *and*
- (c) that firm's maximum and second-highest growth expenditure effectiveness are not both for technology standardization or diversification sets.

Part (a) demonstrates that a firm's maximum growth expenditure effectiveness (i.e. the highest-profits scenario) must be realized by using the new technology. Else, the firm might be able to increase profits by retaining the old technology. Similarly, part (b) guarantees that the minimum growth expenditure effectiveness (i.e. the lowest-profits scenario) does not result with the new technology. Finally, part (c) demonstrates that a firm cannot have a dominant strategy if its ordering reveals a strict preference for technology diversification or standardization.⁹

Proposition 4 can be discussed in the context of Aldrich and Fiol (1994) who state that “[i]ndustries in which founders encourage convergence around a dominant product/service design will gain cognitive legitimacy more quickly than others” (p. 655). (Cognitive legitimacy refers to how quickly the public becomes knowledgeable about the new product's existence and uses.) They also mention that firms may be unable to converge on a design because they each support a different standard. This rationale also holds for our framework. If the maximum growth expenditure effectiveness occurs at $\{1,0\}$ for both firms, then a firm earns more profits by retaining the old technology even if adopting the new one is dominant for its rival.

On the other hand, a firm and its rival may wish to coordinate. Aldrich and Fiol (1994) suggest collaboration among firms to improve the likelihood of a standard being chosen, and our

⁹ Suppose that new customers are most easily attracted to the firm when technology standardization occurs, with e.g. $\beta_i(1,1) > \beta_i(0,0) > \beta_i(1,0) > \beta_i(0,1)$. The firm's manager should adopt the new technology if the rival's manager does so ($\beta_i(1,1) > \beta_i(0,1)$). However, the firm's manager should retain the old technology if the rival's manager does so ($\beta_i(0,0) > \beta_i(1,0)$). Hence, the firm's manager faces no dominant strategy and needs to know her rival's technology choice to select the most profitable technology.

discussion of the wireless industry in the introduction provided an example. By *coordination* we mean that both firms suggest a technology set to the other, with the coordination being successful when both firms agree on a set. Farrell and Saloner (1985) and Belleflamme (1998) discuss the existence of *symmetric excess inertia*, whereby each firm would prefer to adopt the new technology if it knew the other firm would, but both firms retain the old one. Symmetric excess inertia occurred when the firms made sequential technology decisions with partial information, but not when they both had complete information. In our context, we demonstrate that symmetric excess inertia may occur if both firms make simultaneous technology decisions and have complete information, but not if they can coordinate. This exercise allows us to contribute to the studies on when firms should, or not, coordinate (Van Wegberg 2004, Farrell and Saloner 1988).

If neither firm has a dominant strategy, there are either 0 or 2 regret-proof technology sets¹⁰. We note that when there are 2 such sets, at least one firm may be able to increase profits if *both* switch technologies. The 2 sets may be standardization ($\{0,0\}$ and $\{1,1\}$) or diversification ($\{0,1\}$ and $\{1,0\}$). Coordination increases profits if there exists a regret-proof technology set both firms agree on. In other words, if there exists an obvious choice (based on orderings) as to which set maximizes the sum of both firms' profits, then coordination may increase profits. The formal conditions as to when coordination results in a regret-proof set are offered next.

Proposition 5: If 2 regret-proof technology sets exist and both firms have maximum growth expenditure effectiveness for the same set, coordination guarantees the selection of that set.

Corollary to Proposition 5: If 2 regret-proof technology sets exist and both firms have maximum growth expenditure effectiveness for different sets, coordination does not guarantee the selection of any set.

¹⁰ Recall that $P_i(\varphi_i, \varphi_j) > P_i(\varphi'_i, \varphi'_j)$ if and only if $\beta_i(\varphi_i, \varphi_j) > \beta_i(\varphi'_i, \varphi'_j)$. If the firm can order its growth expenditure effectiveness, it can order its profits, and thus there are no mixed strategies given the rival's technology choice. The firm's two pure strategies and the rival's two pure strategies either match, creating two regret-proof technology sets, or clash, creating zero regret-proof technology sets. We note that this result contradicts that of Belleflamme (1998), who found that an equilibrium partition always exists.

As an example of application, consider a firm where new customers prefer technology standardization to diversification; e.g. $\beta_i(1,1) > \beta_i(0,0) > \beta_i(0,1) > \beta_i(1,0)$. That firm's manager cannot adopt the new technology unless she is certain that its rival also does; else the firm may experience its minimum growth expenditure effectiveness, $\beta_i(1,0)$. If the rival's ordering is $\beta_j(1,1) > \beta_j(0,0) > \beta_j(1,0) > \beta_j(0,1)$, that rival's manager experiences the same problem as she does, even if both firms are aware of each other's ordering. As a result, both firms retain the regret-proof set $\{0,0\}$ (the starting set of the game) and earn less profits. Instead, if both managers coordinate, they agree to select $\{1,1\}$ and attract the maximum number of new customers. This reasoning may provide a rationale for the wireless technology firms that, via coordination, standardized around a new technology. However, if the maximum growth expenditure effectiveness is different for each firm, the Corollary to Proposition 5 indicates that coordination should fail. Each manager offers a different technology standardization set to the other, which results in maintaining the status quo. This may provide a rationale for the problem facing supporters of the Blu-Ray and HD-DVD formats.

7. Technology Decision and Existing Sales Acquisition

We now illustrate how the firm's technology adoption decision affects profits via a change in share expenditure effectiveness and, again, offer guidance as to the firm's profit-maximizing technology decision. If, on average, a rival's existing customers perceive a firm's product as being more attractive after a technology change, then that firm's share expenditure effectiveness increases. According to Table 2, such an increase should increase the firm's share expenditures, sales, and profits, but decrease its rival's sales and profits. But if we examine the results of simultaneous changes in share expenditure effectiveness, by symmetry we note that if,

on average, a firm's existing customers perceive the rival's product as being more attractive after a technology change, then the firm's profits decrease. The firm must thus consider the influences on both its and the rival's existing customers. Selecting the first-stage technology that improves the firm's ability to compete for existing sales relative to its rival allows the firm to experience higher returns from second-stage share expenditures.

As in §6, there are 24 distinct orderings for $\rho_i(\varphi_i, \varphi_j)$. We refer to the largest $\rho_i(\varphi_i, \varphi_j)$ as the *maximum share expenditure effectiveness* (i.e. acquiring the maximum number of the rival's existing customers) and the smallest $\rho_i(\varphi_i, \varphi_j)$ as the *minimum share expenditure effectiveness*. To limit duplication, we focus on orderings where adopting the new technology yields maximum effectiveness. We report on optimal strategies based on a firm's ordering. Pure or dominant strategies are obtained when a firm knows the ordering of the rival (which is believable since it involves the acquisition of that firm's customers) as well as its own. Although a firm may be able to estimate these orderings, that firm is unlikely to know the actual magnitude of share expenditure effectiveness for each technology set and the exact effect of its rival's share expenditures on profits. We thus rely on sufficient conditions involving $\rho_i(\varphi_i, \varphi_j)$ and $\rho_j(\varphi_i, \varphi_j)$, whereby if $\rho_i(\varphi_i, \varphi_j) > \rho_i(\varphi'_i, \varphi'_j)$ and $\rho_j(\varphi'_i, \varphi'_j) > \rho_i(\varphi_i, \varphi_j)$, then $P_i(\varphi_i, \varphi_j) > P_i(\varphi'_i, \varphi'_j)$ and $P_j(\varphi'_i, \varphi'_j) > P_j(\varphi_i, \varphi_j)$. We discuss the conditions under which a firm coordinating its technology choice increases that firm's profits.¹¹

¹¹ An example illustrates why technology choices are more complex in §7 than in §6. Suppose that the new technology is more powerful but harder to use than the old one. A firm's maximum share expenditure effectiveness may result when it is the only firm to adopt the new technology (i.e. {1,0}), because the rival's customers on average demand powerful technology. However, at {1,0} that firm's existing customers may switch in the greatest numbers to its rival, because they prefer simpler products. The rival then has maximum share expenditure effectiveness at {1,0}. Thus the firm's manager cannot decide on a technology even if she could anticipate that the rival's manager retains the old technology.

We begin with a situation where, based on the orderings of both firms, the rival possesses no dominant strategy. As a result, the firm cannot anticipate what its rival will do and may regret its decision. We offer sufficient conditions on the orderings of share expenditure effectiveness that lead to dominant strategies, as the firm never regrets its decision if it possesses a dominant strategy. At first glance these conditions may appear difficult to implement, but, for instance for firm i , $\rho_i(1,0) > \rho_j(0,0) > \rho_i(1,1) > \rho_i(0,1)$ and $\rho_j(0,1) > \rho_j(0,0) > \rho_j(1,1) > \rho_j(1,0)$ satisfy these conditions. Formally,

Proposition 6: When a firm cannot anticipate its rival's technology choice and that rival possesses no dominant strategy, adopting the new technology is a dominant strategy if

- (a) the firm's maximum share expenditure effectiveness results when the firm adopts the new technology (i.e. $\{1,0\}$ or $\{1,1\}$);
- (b) the firm's minimum share expenditure effectiveness results when the firm retains the old technology (i.e. $\{0,0\}$ or $\{0,1\}$);
- (c) the firm's maximum and second-highest share expenditure effectiveness are not both technology standardization or diversification sets;
- (d) the rival's maximum share expenditure effectiveness results when the firm retains the old technology (i.e. $\{0,0\}$ or $\{0,1\}$);
- (e) the rival's minimum share expenditure effectiveness results when the firm adopts the new technology (i.e. $\{1,0\}$ or $\{1,1\}$); and
- (f) the rival's maximum and second-highest share expenditure effectiveness are not both technology standardization or diversification sets.

Parts (a), (b), and (c) have the same logic as in Proposition 4. Parts (d), (e), and (f) demonstrate that the adoption of the new technology must result in decreased share expenditure effectiveness for the rival, regardless of that rival's decision. Thus, part (d) guarantees that if the firm adopts the new technology, its rival does not acquire the maximum number of that firm's existing customers. Part (e) indicates that if the firm adopts the new technology, it may be able to

minimize the rival's acquisition of its existing customers. Part (f) indicates that if the firm's existing customers do not prefer standardization or diversification but the firm adopts the new technology, the rival's decision should not cause the firm to regret its decision. Else, the second-highest share expenditure effectiveness for the rival occurs when the firm adopts the new technology, and the firm no longer possesses a dominant strategy. Taken together, parts (c) and (f) make it even more difficult for firms to follow Aldrich and Fiol's (1994) recommendation for standardization. For a firm to possess a dominant strategy (which is a necessary condition for standardization around the new technology), existing customers from both firms must not prefer both standardization sets over both diversification sets. Standardization provides leverage to existing customers by making competing products more substitutable for one another.

When a firm can discern (based on both firms' orderings) that its rival possesses a dominant strategy, we can derive stricter orderings than those in Proposition 6 under which standardization around the new technology is regret-proof for both firms. Formally,

Proposition 7: Both firms should adopt the new technology if

- (a) the firm's maximum share expenditure effectiveness results when it adopts the new technology and technology diversification occurs (i.e. $\{1,0\}$);
- (b) the firm's minimum share expenditure effectiveness results when it retains the old technology and technology diversification occurs (i.e. $\{0,1\}$);
- (c) the rival's maximum share expenditure effectiveness results when it adopts the new technology and technology diversification occurs (i.e. $\{0,1\}$); and
- (d) the rival's minimum share expenditure effectiveness results when it retains the old technology and technology diversification occurs (i.e. $\{1,0\}$).

Thus, as pointed out by Van Wegberg (2004) and Farrell and Saloner (1988), conditions exist under which coordination is unnecessary. Counter-intuitively, standardization around the new technology is not the most profitable set for either firm. Because of parts (a) and (d), either

firm earns its highest profits if diversification occurs and the rival retains the old technology. Thus, each firm possesses a pure strategy of adopting the new technology if its rival retains the old one, which earns the firm its highest profits. Standardization around the old technology is then not regret-proof. But because of parts (b) and (c), either firm earns its lowest profits if diversification occurs. Thus, each firm possesses a pure strategy of adopting the new technology if its rival adopts it too, which prevents the firm from earning its lowest profits. For both firms, either decision for the rival results in the firm adopting the new technology, which then dominates, making standardization around the new technology regret-proof.

The profits a firm earns from standardization around the new technology may even be less than that around the old one. For instance, when $\rho_i(1,0) > \rho_i(0,0) > \rho_i(1,1) > \rho_i(0,1)$ and $\rho_j(0,1) > \rho_j(1,1) > \rho_j(0,0) > \rho_j(1,0)$, standardization around the new technology is guaranteed. Yet, because $\rho_i(1,1) < \rho_i(0,0)$ and $\rho_j(1,1) > \rho_j(0,0)$, $P_i(1,0) > P_i(0,0) > P_i(1,1) > P_i(0,1)$ for firm i . For firm j , $\{1,1\}$ yields the second-highest profits. This example indicates that not all firms must prefer the same standard for it to be adopted. We also note that a similar result can be formulated if, instead, the regret-proof technology set is diversification. Both firms are required to face their maximum and minimum share expenditure effectiveness when standardization occurs. Lastly, in §6 coordination increased the profits of both firms if there were two regret-proof sets – a “win-win” situation. But for share expenditure effectiveness, there is never such a set. There may be a “win-lose” set, in which case the losing firm should not coordinate. For instance, a firm decreases profits but its rival increases profits if they coordinate on $\{1,1\}$ instead of $\{0,0\}$ when $\rho_i(0,0) > \rho_i(1,1)$ and $\rho_j(1,1) > \rho_j(0,0)$. Or, it may be impossible to determine winners and losers, as neither firm can guarantee an increase in profit if they coordinate on $\{1,1\}$

when $\rho_i(0,0) > \rho_i(1,1)$ and $\rho_j(0,0) > \rho_j(1,1)$. Coordination is thus a waste of time and money when existing customers are the main driver for both firms' technology choice.

8. Conclusion and Future Research

This research examined the effects of technology adoption and marketing expenditure decisions on firm performance. For marketing expenditures, we augment the results of Bass et al. (2005) by considering the effects of existing sales on firm performance. We showed that an increase in a firm's existing sales may decrease its profits, but an increase in existing sales or sales retention of a rival may increase that firm's profits. We also demonstrated that an increase in sales retention for either the firm or its rival is likely to benefit both firms.

For the technology adoption decision, we provided guidelines on what a firm should do when it can and cannot coordinate with its rival. We first considered how changes in technology that affect growth expenditure effectiveness affect new sale attraction, sales, and profits. We suggested that a preference for technology standardization over diversification (or vice-versa) among the firm's new customers results in the firm not having a clear technology choice, and showed how this gave new insights into previous research by Aldrich and Fiol (1994). We also contributed to research on positive and negative demand externalities by demonstrating that a customer preference for standardization (positive demand externalities for both technologies) or diversification (negative demand externalities for either technology) is insufficient information for a firm to select a technology. Instead, the firm must be able to coordinate with its rival, and coordination increases profits if firms have maximum effectiveness for attracting new customers for the same technology set. We argued that if one of the firms possesses a dominant strategy, coordination does not increase either firm's profits.

Further, we considered how changes in technology that affect share expenditure effectiveness influence the acquisition of existing customers, sales, and profits. We argued that the conditions under which the new technology dominates also depend on the rival's effectiveness in acquiring the firm's sales. In addition, even if a firm knows its and the rival's effectiveness ordering and can coordinate, we showed that the firm may still regret its technology choice. Coordination itself is worthless. However, we showed that the firms may still select a regret-proof technology set if they both possess dominant strategies and know one another's effectiveness orderings. Thus, standardization without coordination is still feasible, but we showed that each firm settles for its second- or even third-highest profits in that situation.

This research thus demonstrates that the larger hindrance to standardization or adoption of the new technology is the reaction of existing customers to the firm's marketing expenditures, not the reaction of new customers. When the technology decision is only influenced by new customers, the firm only needs to worry about the effects on its own attraction of new customers if the technology set changes, and the firm may be able to coordinate with its rival. Neither is the case when the technology decision is influenced by existing customers.

Extending this work by adding uncertainty on the technology decision's effect on marketing is likely to significantly inform this line of research. Further research is also required on the modeling of the marketing component of the decision problem. We assume no retention expenditures because the product is new. While less emphasis on customer retention is required for new products where competition for customers is not yet significant, there are still costs associated with retaining existing customers. Also, the model herein can be extended to better incorporate profit differences between new and existing customers. Last, the model only contains a word-of-mouth effect rather than a consideration of price elasticity. There is much to be done

in further investigating the technology choice and marketing expenditures associated with new products and we hope that others join us in this effort.

Appendix

Solving the second stage. The second order conditions for optimality are met (and there exists a unique optimal solution) if the profit function is concave with respect to a_i and w_i . The second order derivatives are, respectively,

$$\frac{\partial^2 P_i}{\partial^2 a_i} = -\lambda_i [1 - \lambda_i] \rho_i(\varphi_i, \varphi_j) a_i^{-\lambda_i - 1} \delta_j S_{j,0} < 0$$

$$\frac{\partial^2 P_i}{\partial^2 g_i} = -\mu_i [1 - \mu_i] \beta_i(\varphi_i, \varphi_j) g_i^{-\mu_i - 1} [m_0 - S_{i,0} - S_{j,0}] < 0.$$

Since cross-derivatives are 0, the Hessian matrix is negative definite. We can solve for optimal share expenditures via first order conditions. Formally, $\frac{dP_i}{da_i} = [1 - \lambda_i] \rho_i(\varphi_i, \varphi_j) a_i^{-\lambda_i} \delta_j S_{j,0} - 1 = 0$ if

and only if $a_i^{-\lambda_i} = \left[\frac{1}{[1 - \lambda_i] \rho_i(\varphi_i, \varphi_j) \delta_j S_{j,0}} \right]$, or, equivalently, $a_i^* = \left[[1 - \lambda_i] \rho_i(\varphi_i, \varphi_j) \delta_j S_{j,0} \right]^{\frac{1}{\lambda_i}}$.

Similarly, $g_i^* = \left[[1 - \mu_i] \beta_i(\varphi_i, \varphi_j) [m_0 - S_{i,0} - S_{j,0}] \right]^{\frac{1}{\mu_i}}$.

Proof of Proposition 4. By definition, a firm's dominant strategy must be the same regardless of its rival's technology choice. The new technology is thus dominant if and only if $\beta_i(1,0) > \beta_i(0,0)$ and $\beta_i(1,1) > \beta_i(0,1)$. We first prove by contradiction that if $\beta_i(1,0) > \beta_i(0,0)$ and $\beta_i(1,1) > \beta_i(0,1)$, then parts (a), (b), and (c) follow. Suppose (a) does not hold, then $\beta_i(0,0)$ or $\beta_i(0,1)$ is the maximum, and $\beta_i(1,0) > \beta_i(0,0)$ or $\beta_i(1,1) > \beta_i(0,1)$ does not hold. Suppose (b) does not hold, then $\beta_i(1,0)$ or $\beta_i(1,1)$ is the minimum and $\beta_i(1,0) > \beta_i(0,0)$ or $\beta_i(1,1) > \beta_i(0,1)$ does not hold. Suppose (c) does not hold. If technology standardization is the maximum and second-highest share expenditure effectiveness, then $\beta_i(1,0) > \beta_i(0,0)$ does not hold. If technology diversification is the maximum and second-highest share expenditure effectiveness, then $\beta_i(1,1) > \beta_i(0,1)$ does not hold.

We prove by construction that if parts (a), (b), and (c) hold, then $\beta_i(1,0) > \beta_i(0,0)$ and $\beta_i(1,1) > \beta_i(0,1)$. Assume parts (a) and (b) hold, then the ordering must be $\{\beta_i(1,1) \text{ or } \beta_i(1,0)\} > \{\beta_i(1,0) \text{ or } \beta_i(1,1) \text{ or } \beta_i(0,1) \text{ or } \beta_i(0,0)\} > \{\beta_i(0,1) \text{ or } \beta_i(0,0)\}$. Assume part (c) holds. Then if $\beta_i(1,1)$ is the maximum share expenditure effectiveness, the ordering must be $\{\beta_i(1,1)\} > \{\beta_i(1,0) \text{ or } \beta_i(0,1)\} > \{\beta_i(1,0) \text{ or } \beta_i(0,1) \text{ or } \beta_i(0,0)\} > \{\beta_i(0,1) \text{ or } \beta_i(0,0)\}$. Testing all possible orderings of the above, in each $\beta_i(1,1) > \beta_i(0,1)$ and $\beta_i(1,0) > \beta_i(0,0)$. The same holds for $\beta_i(1,0)$ as the maximum share expenditure effectiveness.

Proof of Proposition 5. If there are two regret-proof technology sets, the maximum growth expenditure effectiveness must come from one of those two sets. If the maximum growth expenditure effectiveness is from the same technology set for both firms, than both firms will prefer that set to all other sets. Otherwise, the firms prefer different technology sets.

Proof of Proposition 6. This result is proven by construction via repetitively applying the fact that if $\rho_i(\varphi_i, \varphi_j) > \rho_i(\varphi'_i, \varphi'_j)$ and $\rho_j(\varphi'_i, \varphi'_j) > \rho_i(\varphi_i, \varphi_j)$ then $P_i(\varphi_i, \varphi_j) > P_i(\varphi'_i, \varphi'_j)$ and $P_j(\varphi'_i, \varphi'_j) > P_j(\varphi_i, \varphi_j)$.

Proof of Proposition 7. Assume parts (a) and (d) hold. Firm i 's profit ordering is then $P_i(1,0) > \{P_i(1,1), P_i(0,0), P_i(0,1)\}$ and $\{P_j(1,1), P_j(0,0), P_j(0,1)\} > P_j(1,0)$. Additionally assuming that parts (b) and (c) hold, $P_i(1,0) > \{P_i(1,1), P_i(0,0)\} > P_i(0,1)$ and $P_j(0,1) > \{P_j(1,1), P_j(0,0)\} > P_j(1,0)$. Thus, the firm should always select the new technology (1) if its rival selects either the old (0) or the new (1) one. Selecting the new technology is thus the dominant strategy for both firms.

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Table 1. Notation summary (firm i)

| Type | Description | Notation |
|---------------------------------|--|---------------------------------|
| Decision variables | Technology adoption | φ_i |
| | Share expenditures | a_i |
| | Growth expenditures | g_i |
| Functions of decision variables | Share expenditure effectiveness | $\rho_i(\varphi_i, \varphi_j)$ |
| | Growth expenditure effectiveness | $\beta_i(\varphi_i, \varphi_j)$ |
| | Sales | S_i |
| Parameters | Unit profit margin | π_i |
| | Existing sales | $S_{i,0}$ |
| | Returns of share expenditures | λ_i |
| | Returns of growth expenditures | μ_i |
| | Sales Retention | δ_i |
| | Word-of-mouth effect of existing sales | ε_i |
| | Market ceiling | m_0 |

Table 2. Sensitivity of marketing expenditures and firm performance

| Increases in | | Firm i | | | | Firm j | | | |
|--|---------------------------------|-------------------------------|--------------------------------|------------------|--------------------|-------------------------------|--------------------------------|------------------|--------------------|
| Description | Notation | Share expenditures a_i^* | Growth expenditures g_i^* | Sales S_i^* | Profits P_i^* | Share expenditures a_j^* | Growth expenditures g_j^* | Sales S_j^* | Profits P_j^* |
| Unit profit margin | π_i | ↑ | ↑ | ↑ | ↑ | – | – | ↓ | ↓ |
| Existing sales | $S_{i,0}$ | – | ↓ | NM | NM | ↑ | ↓ | NM | NM |
| Share expenditure effectiveness | $\rho_i(\varphi_i, \varphi_j)$ | ↑ | – | ↑ | ↑ | – | – | ↓ | ↓ |
| Growth expenditure effectiveness | $\beta_i(\varphi_i, \varphi_j)$ | – | ↑ | ↑ | ↑ | – | – | – | – |
| Sales retention | δ_i | – | – | ↑ | ↑ | ↑ | – | ↑ | ↑ |
| Word-of-mouth effect of existing sales | ε_i | – | – | ↑ | ↑ | – | – | – | – |
| Market ceiling | m_0 | – | ↑ | ↑ | ↑ | – | ↑ | ↑ | ↑ |

Key: ↑ for increase, ↓ for decrease, – for unchanged, NM for non-monotonic

Table 3. Necessary conditions on profits to ensure a pure Nash equilibrium technology set

| | Firm j retains old technology ($\varphi_j = 0$) | Firm j switches to new technology ($\varphi_j = 1$) |
|--|--|--|
| Firm i retains old technology ($\varphi_i = 0$) | $P_i(0,0) > P_i(1,0)$ | $P_i(0,1) > P_i(1,1)$ |
| | $P_j(0,0) > P_j(0,1)$ | $P_j(0,1) > P_j(0,0)$ and $P_i(0,0) > P_i(1,0)$ or $P_j(1,1) > P_j(1,0)$ |
| | Cell A | Cell B |
| Firm i switches to the new technology ($\varphi_i = 1$) | $P_i(1,0) > P_i(0,0)$ | $P_i(1,1) > P_i(0,1)$ |
| | $P_j(1,0) > P_j(1,1)$ and $P_i(1,1) > P_i(0,1)$ or $P_j(0,0) > P_j(0,1)$ | $P_j(1,1) > P_j(1,0)$ and $P_i(1,0) > P_i(0,0)$ or $P_j(0,1) > P_j(0,0)$ |
| | Cell C | Cell D |

The first two inequalities in any Cell ensure that the technology set is regret-proof for both firms. If the technology set is $\{0,0\}$, the starting point of the game, the first two inequalities are sufficient to guarantee standardization around the old technology; neither firm has an incentive to switch to the new technology. Thus, no matter how much more profitable the technology set $\{1,1\}$ may be for both firms, the firms retains the old technology if doing so is regret-proof for both firms. If the technology set is not $\{0,0\}$, a third inequality must also be satisfied. The third inequality in Cells B, C or D means that if the technology set represents technology standardization (or diversification), the other technology standardization (or diversification) must not be regret-proof. For example, the third inequality for $\{1,1\}$ signifies that at least one of the firms can make more profits by adopting the new technology even though the other firm retains the old technology. The importance of this third inequality for $\{1,1\}$ is that the new technology must be robust enough that a firm can increase profits by adopting it even if its rival retains the old technology. Thus, a firm should not adopt a new technology just because it would increase profits if its rival also adopted the new technology; instead, a firm should adopt the new technology only if it is sure to increase profits no matter what its rival decides.